

RF Microphotonics for NASA Space Communications Applications

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An RF microphotonic receiver has been developed at Ka-band. The receiver consists of a lithium niobate micro-disk that enables RF-optical coupling to occur. The modulated optical signal (~ 200 THz) is detected by the high-speed photonic signal processing electronics. When compared with an electronic approach, the microphotonic receiver technology offers 10 times smaller volume, smaller weight, and smaller power consumption; greater sensitivity; and optical isolation for use in extreme environments. The status of the technology development will be summarized, and the potential application of the receiver to NASA space communications systems will be described.

RF Microphotonics for NASA Space Communications

Applications

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Vision for Space Exploration

- Retire Space Shuttle (2010)
- Build Crew Exploration Vehicle (2014)
- Build Crew Launch Vehicle and Heavy Lift Launch Vehicle (2014)
- Complete International Space Station (2010)
- Extend human expeditions to the Moon (2018)
- Explore Solar System and beyond (> 2030)

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Benefits of Optical Communications:

- Higher gains and higher data rates
- Potential for low mass (low-weight payloads), small size (receivers/ transmitters), and low power consumption
- High bandwidth (> 1 GHz)
- Narrow beams (communications security)

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Purpose of this Effort:

Develop advanced communication receiver components with a 5x to 10x reduction in volume and power consumption compared to current state-of-the-art while maintaining high data rates.

Background Information:

- Lithium niobate (LiNbO_3) microdisk modulator (whispering gallery modes)
- High-Q microdisk optical resonators: $10^6 < Q_{\text{opt}} < 6 \times 10^6$
- Optical free spectral range (FSR): $7 \text{ GHz} < n_{\text{FSR}} < 43 \text{ GHz}$
- Laser wavelength: 1.5 microns
- Microdisk diameter: 1- to 6-millimeter range

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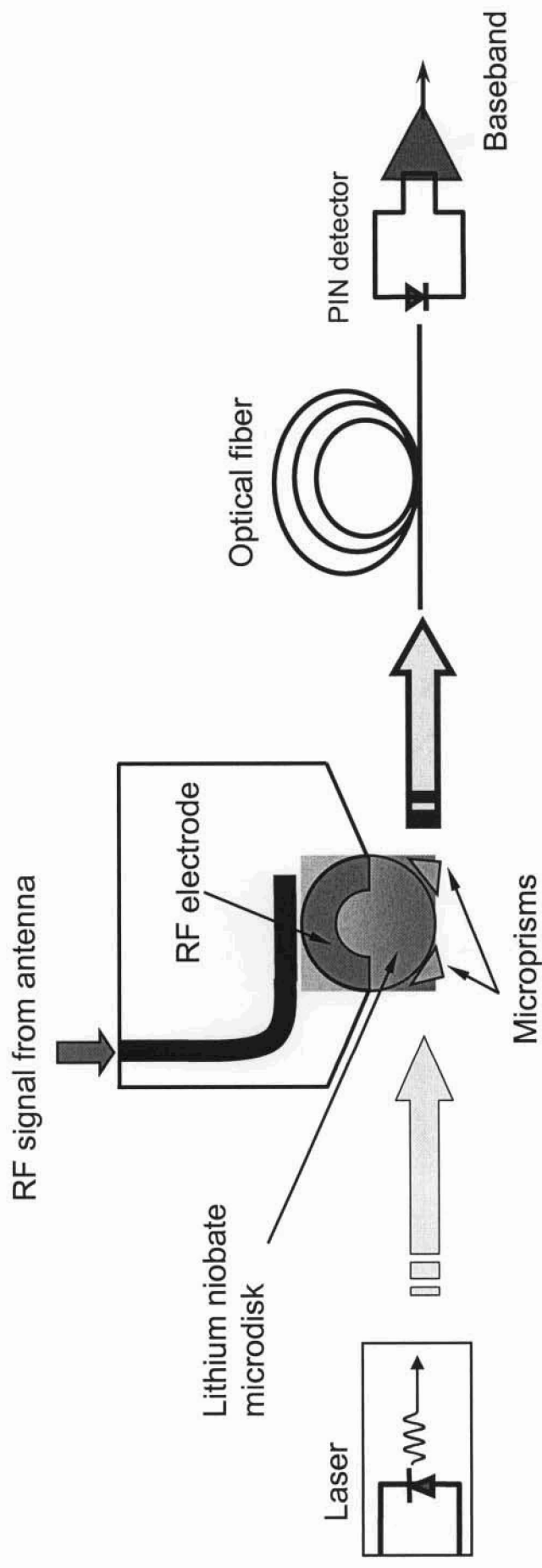


Background Information (continued):

- Microdisk thickness: 190 to 700 microns
- High-Q RF ring resonator: $70 < Q_{\text{RF}} < 90$
- Electro-optical resonance
- Critical RF and optical coupling
- Modulation: linear at the fundamental; as well as second and third harmonics



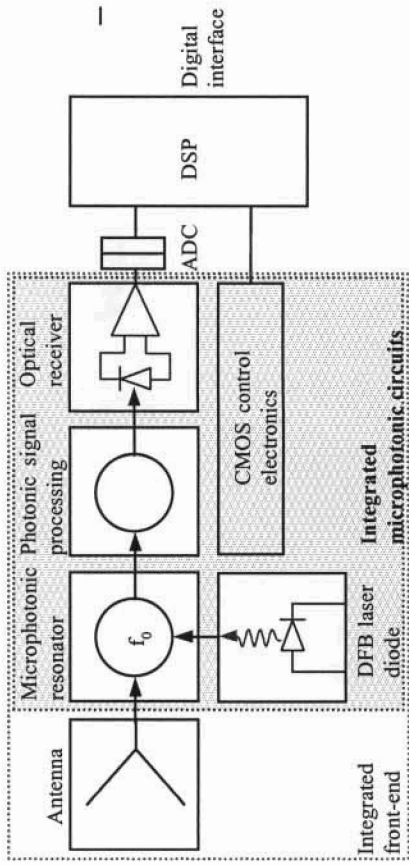
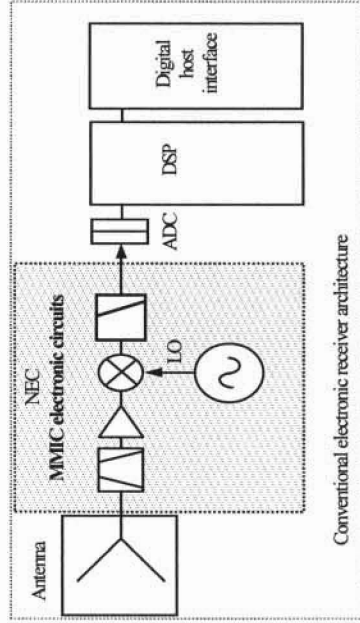
Schematic diagram of the RF microphotonic receiver components.



Source: USC



Comparison of basic concept for RF receiver in microwave and photonic approaches.

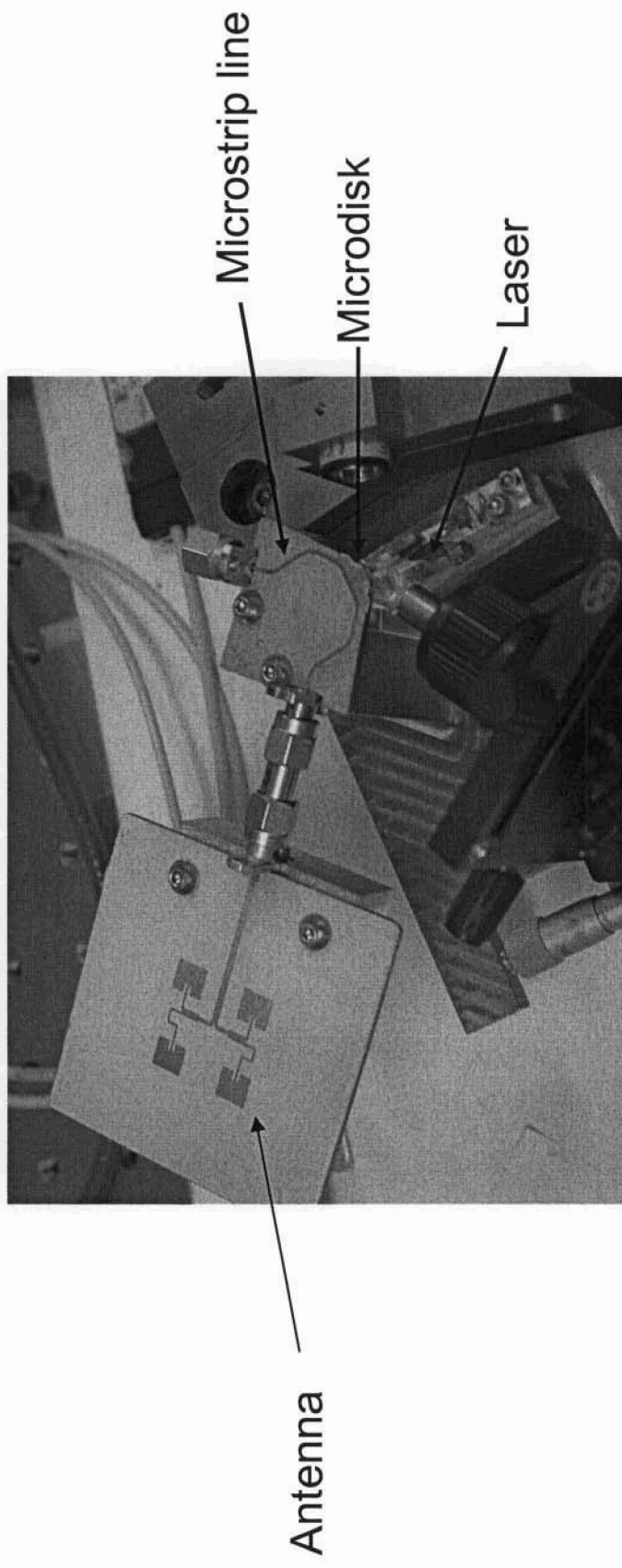


- Conventional electronic receiver architecture.
 - 60 GHz receive *electronic* analog RF front-end module developed by NEC
 - 0.4 W power consumption
 - Volume of 900 mm³
 - Ref.: Ohata et al., IEEE, MTT 44, 2354 (1996)

- Microphotonic RF receiver architecture.
 - Laser diode is 200 THz LO
 - 60 GHz carrier frequency
 - 4 mW power consumption
 - Volume less than 40 mm³



RF microphotonic set-up showing the components.

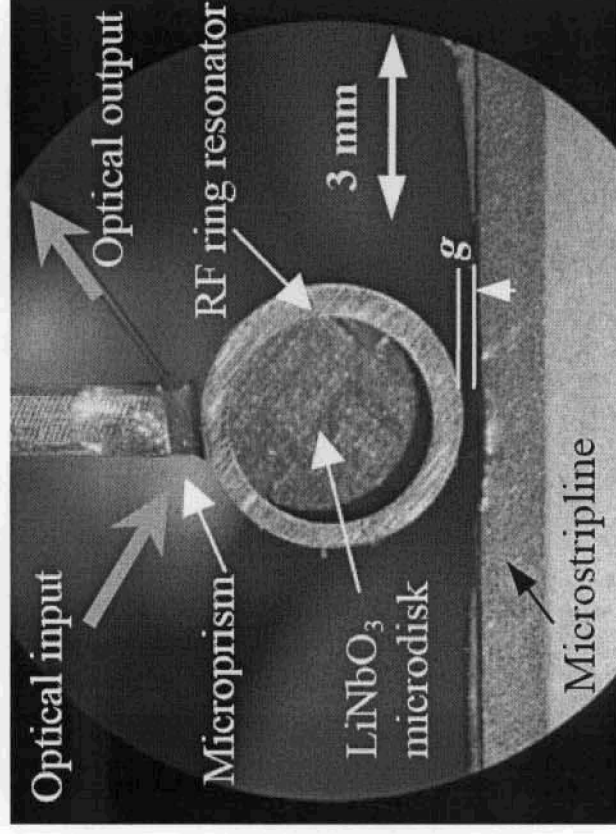


Source: USC

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Close-up of microdisk.



Source: USC

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Operational Characteristics:

- Linear modulation (demonstrated modulation frequency)
 - C-band: 7.6 GHz and 8.7 GHz
 - Ku-Band: 14.5 GHz, 14.8 GHz , 15.2 GHz (SHM) and 17.4 GHz (SHM)
 - Ka-Band: 26 GHz (THM) and 29.6 GHz (SHM)
 - Q-Band: 44.4 GHz (THM)
- Wireless data and video transmission (down-conversion with RF mixer)
 - C-band: 8.7 GHz
 - Ku-Band: 15.2 GHz

NOTE: SHM – second harmonic modulation; THM – third harmonic modulation

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Operational Characteristics (continued):

- Data rates
10, 50, and 100 Mb/s
- Sensitivity
Linear modulation: -85 dBm
- Ku- and Ka-band photonic RF-receiver
- Digital photoreceiver (bandwidth: 100 MHz; sensitivity: -34.5 dBm)
- Tunable laser (wavelength resolution: 0.03 picometers, linewidth: 400 kilohertz)



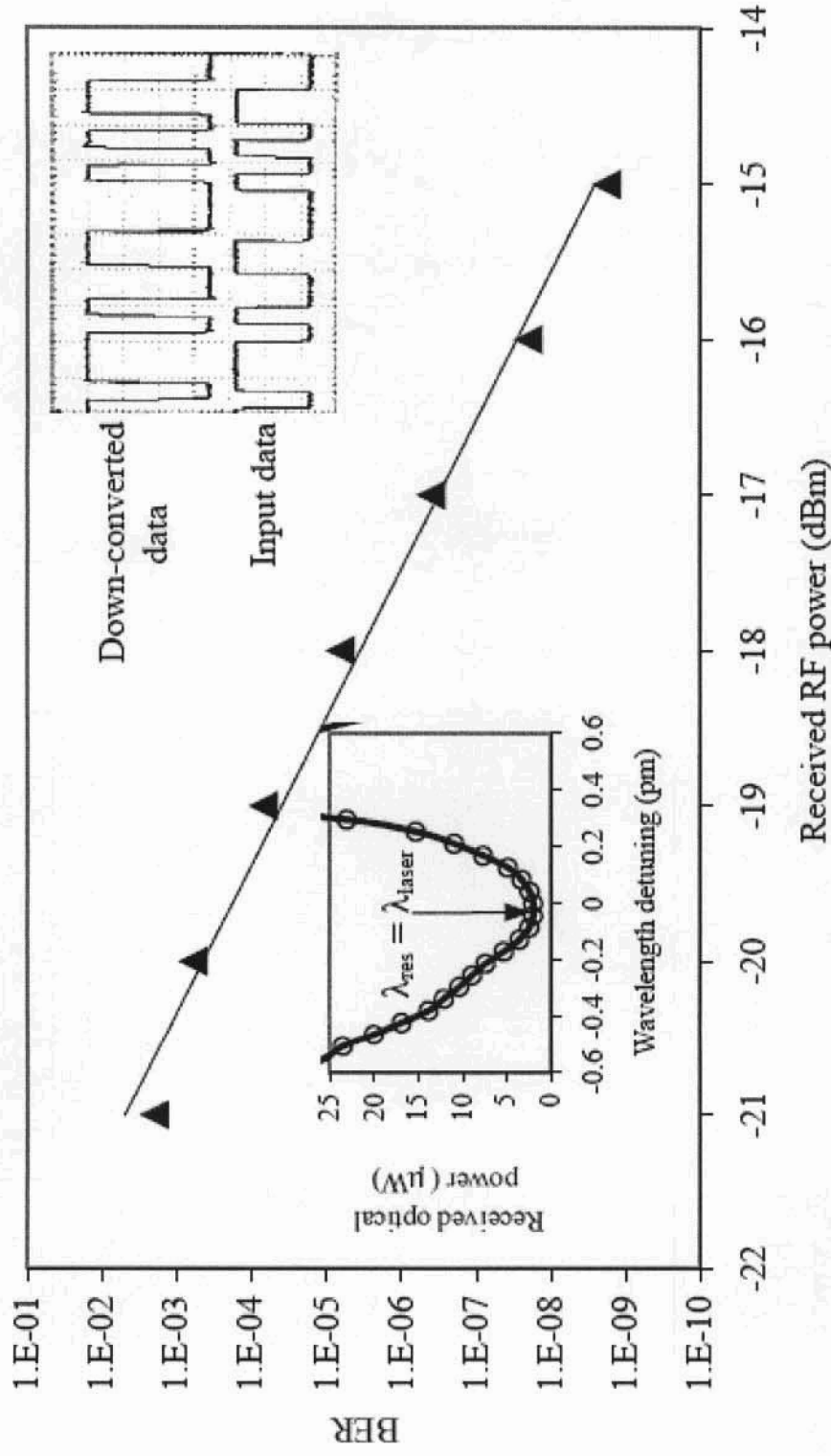
Operational Characteristics (continued):

- Planar antenna array capability
- Laboratory-level microphotonic receivers have been developed
- An 8.7-GHz receiver has been shipped to NASA GRC for testing and evaluation
- Integration effort conducted at NASA GRC
- NASA technology readiness level (TRL) 3

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Bit error rate as a function of received RF power.

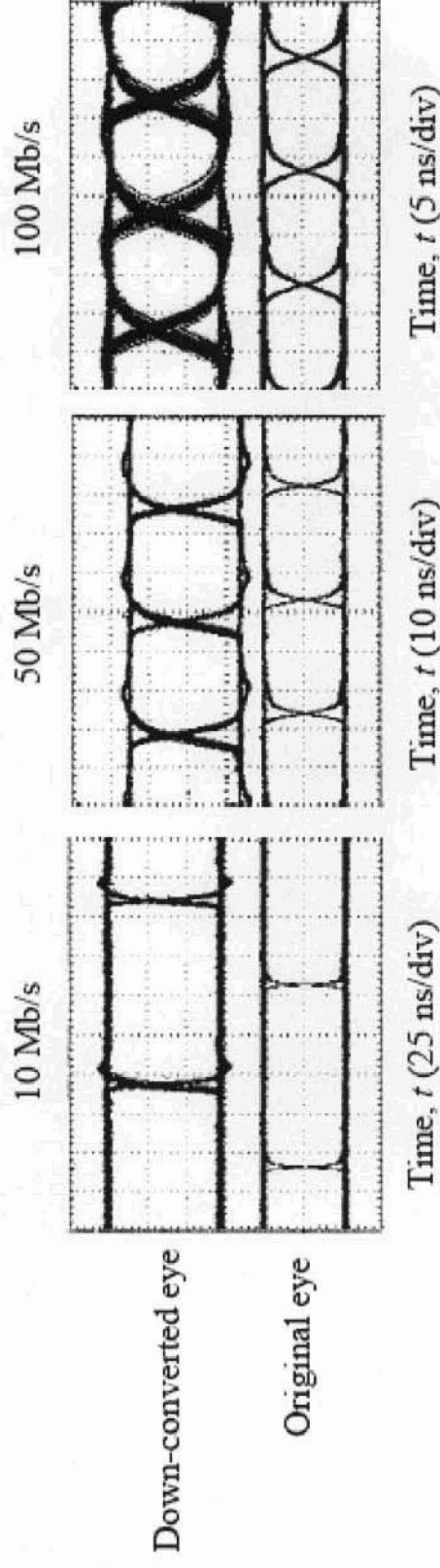


Bit error rate versus received RF power. The frequency is 14.6 GHz. The right inset shows the data in the time domain. The whispering gallery mode resonance is indicated in the left inset (source: USC).

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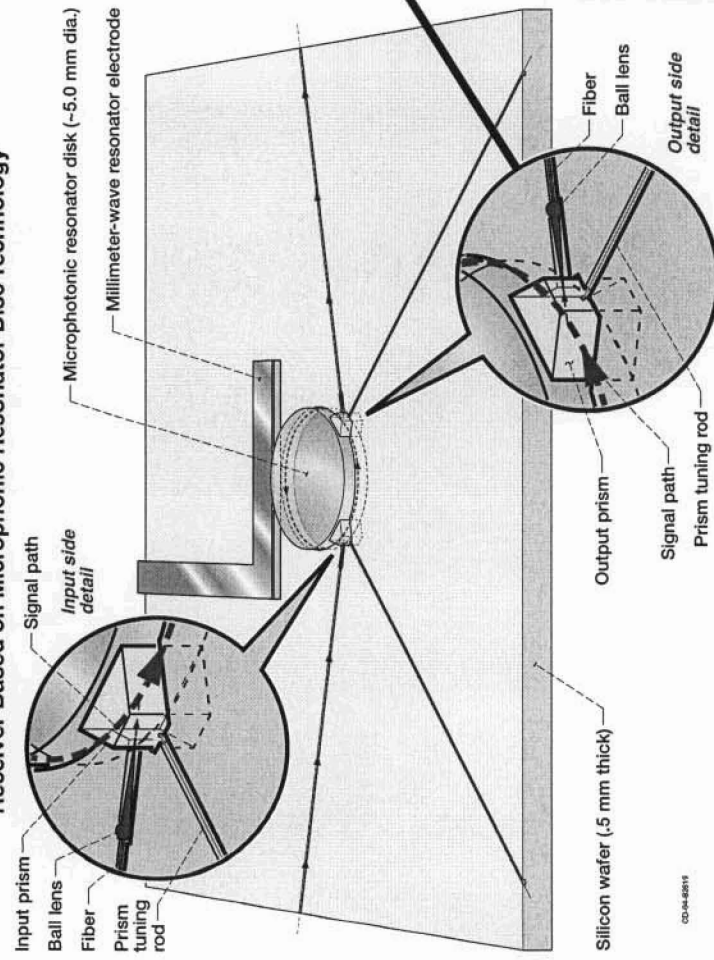
Eye diagrams for different data rates.



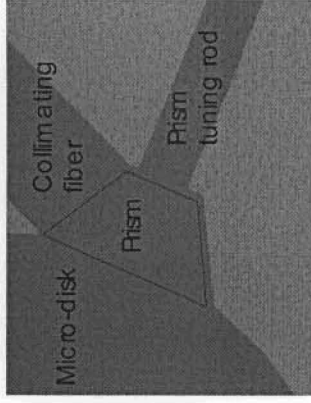
Eye diagrams for 10 Mbps, 50 Mbps, and 100 Mbps. The frequency is 14.6 GHz, and the received RF power is -15 dBm (source: USC).

Packaging of RF micro-disk-based photonic receiver integrated on silicon wafer.

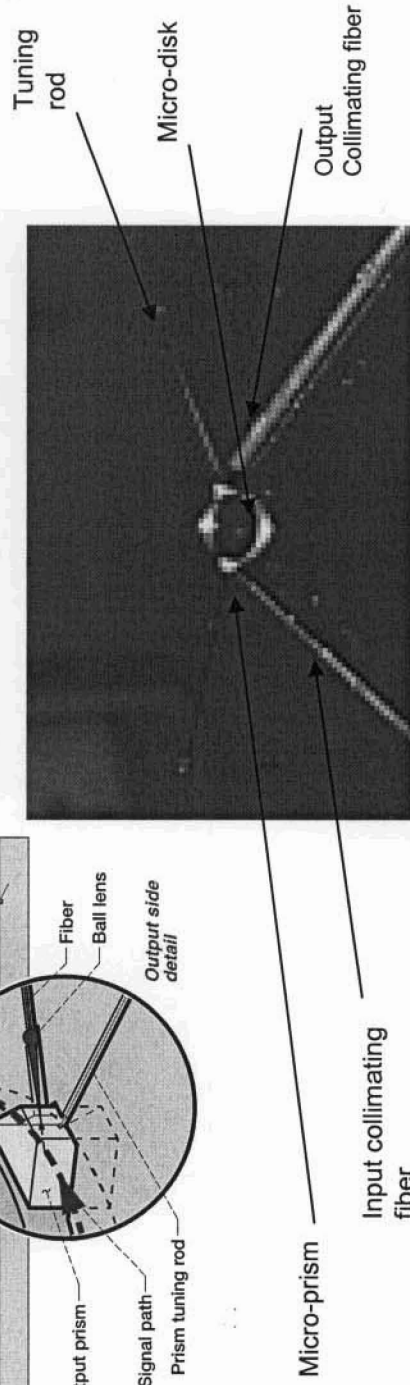
Detail of On-Chip Component Integration for mm-Wave Receiver Based on Microphonic Resonator Disc Technology



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SEM picture of etched region on silicon wafer, the micro-disk, collimating fiber, prism, and tuning rod cavities.



Photograph of micro-disk based photonic receiver integrated on-chip silicon wafer to validate packaging concept. The on-chip integration shows input fiber/output collimating fiber, two micro-prisms, micro-disk, and two prism tuning rods.



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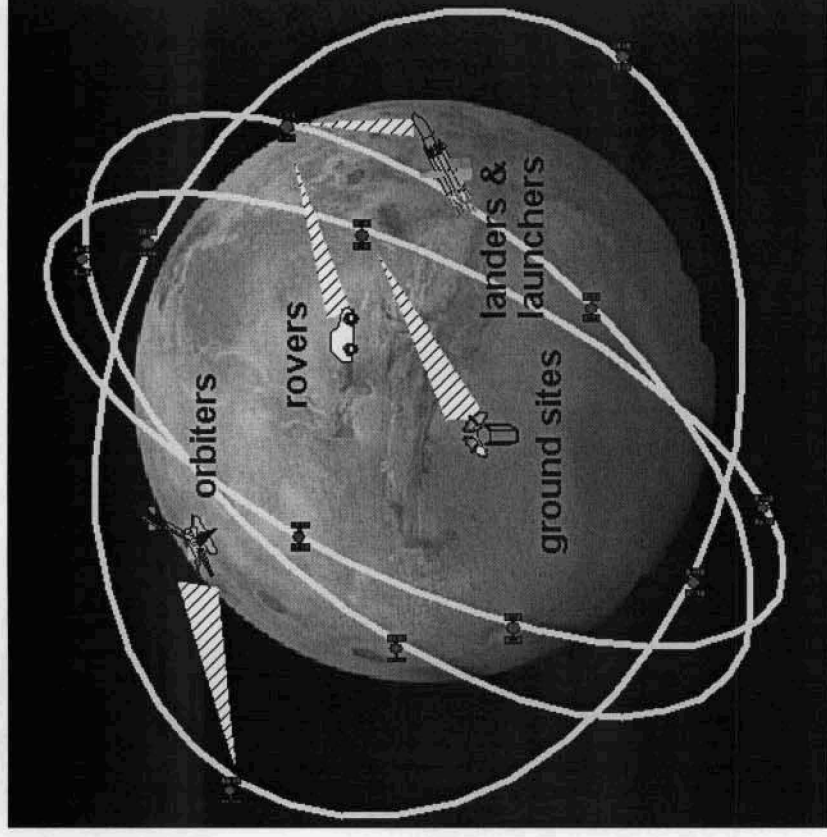
Potential Applications:

- Surface wireless communications networks
- Novel receiver technologies in support of robotic systems, rovers, landers, spacecraft, habitats, and astronauts
- Integration with phased array subsystems/sensor networks
- Science data acquisition

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Potential Applications for Planetary Exploration.



Source: USC

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Summary:

- Application of RF/optical technologies
- Optical isolation
- Small volume
- Low weight
- No high-speed electronics
- Low power consumption

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Summary (continued):

- LO and RF mixer eliminated
- Reduced complexity
- High data rates (> 100 Mbps)
- Extension to mm-wave frequencies (smaller microdisk, harmonic modulation)
- Insertion opportunities for space communications test beds in support of the Vision for Space Exploration

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